APPENDIX A

FAR ULTRAVIOLET SPECTROSCOPIC EXPLORER (FUSE) GUEST INVESTIGATOR PROGRAM AND MISSION DESCRIPTION – Cycle 3

A.1 Guest Investigator (GI) Program Description

A.1.1 Overview

The Far Ultraviolet Spectroscopic Explorer (FUSE) provides high-resolution (R ~20,000) spectroscopy at far ultraviolet (FUV) wavelengths (905-1187 Å) with sufficient sensitivity to study a wide variety of objects, including many extragalactic lines of sight. FUSE was launched on June 24, 1999. Normal science operations for the three-year prime mission began on December 1, 1999. A two-year extended mission phase is planned. A brief description of the FUSE mission is provided in Section A.2

Under this NRA, NASA seeks a scientifically meritorious FUSE GI program for Cycle 3, the last year of the prime mission. GI observing programs should exploit the unique capabilities of FUSE but the content and scope of GI programs must be consistent with the mission capabilities and the observing program policies and guidelines discussed below. Cycle 3 science observations will take place during a 12-month period beginning in December 2001.

Proposals submitted in response to this NRA constitute the first phase of the FUSE GI proposal process. Information required during this proposal phase includes the scientific justification, observation descriptions, astronomical target data, exposure times, and any special operational requirements (e.g., orientation constraints, timing considerations, etc.). After selection by NASA, successful GIs must submit detailed observing plans to the FUSE Science Center at the John Hopkins University (JHU) so that detailed planning, feasibility assessment, and observation scheduling can be performed.

FUSE observing time is made available to the international astronomical community through peer-reviewed proposals. NASA has allocated approximately half of the mission's observing time over three years to the GI program. The other half of the observing time was allocated, primarily in Cycle 1 and 2, to the FUSE PI Team to address certain high-priority scientific problems described in Section A.2.1. About 75% of the total FUSE science observing time in Cycle 3 will be allocated to GI programs (Section A.1.2).

Section A.1.3 describes some important capabilities and constraints that affect how GI programs will be evaluated and implemented in Cycle 3.

Special attention is directed to the fact that there are two types of unscheduled observing time that can be made available with the approval of the FUSE Project Scientist. The first deals with major Targets of Opportunity (ToO), such as supernovae, novae, and comets (see Section A.1.5). The second type, called Project Scientist's Discretionary Observing Time, is intended for observations of an urgent nature requiring a small amount of observing time and are of sufficiently high scientific priority that the observation should not be delayed to the next observing cycle (see Section A.1.6).

The policies concerning FUSE targets are summarized in Section A.1.8. FUSE PI Team science program abstracts and their targets reserved for Cycle 3 are available from the FUSE GI program Web site. With specific exceptions (see Sections A.1.8), there are no science investigations reserved for the PI team but there are reserved targets. The scientific goals of GI proposals may overlap with those of the FUSE PI Team as long as different targets are observed.

A.1.2 Observing Time Allocation

FUSE observing time in Cycle 3 will be allocated in on-target exposure time in units of kiloseconds (ksec). Proposals should request only the time needed for scientific exposures. After accounting for instrument calibration, target acquisition, satellite maneuvering, and operational overhead, NASA anticipates that ~5700 ksec of on-target exposure time will be allocated to GI programs in Cycle 3. In Cycles 1 and 2 the average GI observing program size was 50 ksec. About 26% of the Cycle 2 GI time was allocated to programs with more than 80 ksec.

- **Large Observing Programs** – These are an essential part of the FUSE science program, and they can provide the observing resources to address significant and/or difficult observing programs. NASA expects to allocate up to 1500 ksec across the whole FUSE GI program in Cycle 3 specifically for programs needing more than 150 ksec. Such proposals should be written according to the same guidelines and instructions as other FUSE proposals and will be reviewed with other proposals in the same research category. Recommendations for how the time for large observing programs should be allocated will then be determined when the review panel chairs meet following the reviews by the individual panels.

- **Small Observing Programs** – Due to the difficulties associated with administering many very small programs, **each Cycle 3 FUSE GI proposal must request a minimum of 10 ksec of on-target exposure time**. If the proposal has only one target, the exposure time on that object must be at least 10 ksec. A proposal having multiple targets can have exposure times of less than 10 ksec per target as long as the total exposure time for the proposal is at least 10 ksec.

- **Short Exposures** – An observing program’s time allocation will be charged 4 ksec for each short exposure. If a target has an exposure time less than 4 ksec, the program will be charged 4 ksec for that observation to account for the extra overhead associated with short-duration observations. The FUSE mission planning system was designed to support a pool of observations that requires on average no more than three pointing maneuvers per day. Short exposures should not be arbitrarily extended to 4 ksec if the required S/N is expected to be reached in a shorter time.

- **Observing Program Duration** – Proposers may only request observations to be executed during the nominal 12-month period of Cycle 3 (i.e., multi-cycle proposals will not be accepted). If proposers want to continue their scientific programs over multiple cycles, they must repropose their investigations in subsequent GI cycles.

NASA intends that all approved regular (i.e., non-ToO) observing programs will be executed. If necessary, regular observing programs will be carried over into Cycle 4 if they are not executed during Cycle 3. GI's do not need to repropose for these observations, and any such programs will be given priority for execution in Cycle 4. However, ToO programs will **not** be carried over into the next Cycle. GI's must repropose any ToO programs that are not activated and executed within the nominal one-year observing cycle.

A.1.3 Mission Capabilities and Constraints During Cycle 3

Several important factors bearing on the design of Cycle 3 observing programs are summarized in this section. Complete details are available from the FUSE Observer's Guide, available online at http://fuse.pha.jhu.edu/support/guide/obsguide.html.

- **Satellite Orientation** – Observations are normally scheduled in the range 30˚ < *beta* < 85˚ in order to maintain coalignment of the four spectroscopic channels, where *beta* is defined as the angle between the anti-sun direction and the telescope boresight. (The solar orientation of the satellite is restricted to beta angles between 15˚ and 105˚..) Observations may be scheduled outside the normal *beta* angle range only with strong scientific or technical justification. For example, observations in the Large Magellanic Cloud, always at *beta* = 90˚, are usually scheduled only at certain times when they are in the satellite's continuous viewing zone.

- **Channel Coalignment** – The relative alignment of the four optical channels is sensitive to changes in the satellite's thermal environment in orbit. In particular, significant changes in the orientation of FUSE with respect to the Sun can cause the channel alignments to drift relative to one another. This is particularly a concern for the SiC channels, as they are located on the side of the satellite that faces the Sun. Channel coalignment is maintained operationally by managing changes in *beta* angle and other procedures.

Spectrograph Apertures – The default spectrograph aperture is the LWRS (see Table A-1), which should be suitable for the vast majority of observing programs. Proposals must provide specific scientific justification for the use of the MDRS and HIRS apertures. Legitimate reasons to use these apertures include: (a) to reduce spectral contamination from terrestrial airglow, (b) to reduce spectral contamination from diffuse nebular emission near the target, (c) to eliminate spectral contamination from FUV-bright objects close to the target (e.g., crowded fields), and (d) to achieve higher spectral resolution when observing diffuse targets.

The acquisition of SiC (short wavelength) data may be more difficult than the acquisition of LiF data when using the MDRS aperture, so proposers should discuss the relative priority of the SiC and LiF data when the MDRS aperture is requested.

Use of the HIRS aperture is restricted to the LiF1 channel during Cycle 3, and the scientific justification for using this aperture must be clearly discussed in the proposal.

Table A-1. FUSE Aperture Sizes, Throughput and Spectral Resolution

Aperture	Acronym	Dimensions (arcsec)	Effective Point Source Throughput[1]	Spectral Resolution ($\lambda/\Delta\lambda$)
Default Aperture	LWRS	30 x 30	1.00	~20,000 (point source) 3,000 (diffuse source)
Medium Slit	MDRS	4 x 20	0.98	~20,000 (point source)
Narrow Slit	HIRS	1.25 x 20	0.55 (LiF1)	≥20,000 (point source)

[1] Target centered in aperture, nominal pointing jitter.

- **Instrument Performance** – The FUSE instrument routinely obtains data with a spectral resolving power of R~20,000 and a S/N ratio of ~30:1 in a 0.05 Å resolution element over most of the wavelength range.

  Recent tests have demonstrated that higher S/N ratio spectra can be obtained with special observing techniques. **Cycle 3 proposers may request S/N up to 100 per 0.05Å resolution element**. See the FUSE Observers Guide for details and restrictions.

- **Exposure Times and Channel Selection** – Because the FUSE spectral resolution varies with wavelength and from channel to channel at a given wavelength, it may not always be possible to combine data from different channels and maintain the desired spectral resolution. Proposers should consider whether to define their exposure times based on achieving a desired S/N ratio in a single channel if the spectral resolution requirements exceed R ~10,000. This, in effect, reduces the effective area of the instrument but ensures that there are adequate counts to meet the resolution and S/N requirements.

- **Exposure Times And Observations Obtained During Orbital Night** – Observations of fainter objects in the LWRS aperture may be adversely affected by terrestrial air glow emission These effects can be significantly reduced by analyzing only the night-time portion of the obtained data set. Because FUSE cannot easily be retargeted within orbits, the scheduling of night-only observing is extremely inefficient, and there is, therefore, no "night-only" mode of observing with FUSE. If an observation requires a significant amount of night-time data, the desired night exposure time must be increased by a factor of 1.6 to obtain the proper time allocation. See the FUSE Observer's Guide for details.

- **Constrained Observations** – FUSE observations with strong scheduling constraints, such as those made in coordination with other telescopes, can be accommodated on a limited basis due to other FUSE scheduling constraints (restricted *beta* angles, ram avoidance, etc). Proposers must identify any such constrained observations in their proposals. The peer review panels will assess the criticality and potential benefits of these observations when evaluating the scientific merit of the proposal. The FUSE Project expects to be able to support ~25 constrained observations during Cycle 3 (about one every two weeks). This includes all time critical and moving target observations for both GI and PI-team programs.

  Decisions on when Cycle 3 observations will be scheduled can be made only after Phase 2 data for accepted programs have been submitted and reviewed. The final scheduling decisions will be made by the FUSE PI after consulting with the FUSE NASA Project Scientist, taking into account any recommendations of the proposal review panels. Any requests for coordinated observations received after proposal acceptance by NASA, but not identified in the original proposal, will be reviewed by the FUSE Project Scientist. Approval of such late requests for constrained observations will be made on a case by case basis prior to any scheduling activity by the FUSE Project.

- **Sensitivity Limits** – There are fundamental detector performance limitations for both faint ($F_\lambda \leq 5 \times 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1}) and bright ($F_\lambda > 3 \times 10^{-11}$ erg cm^{-2} s^{-1} Å^{-1}) targets. Proposers expecting to observe objects near either extreme should consult the FUSE Observer's Guide for further information and restrictions.

- **Moving Targets** – Recent tests have demonstrated the capability of FUSE to observe moving targets. The flight software has been tested at rates up to 0.2 arcsec/sec, although actual Solar System observations to date have only been made in the Jovian and Saturnian systems (i.e., much slower rates).

  Proposers should be aware that only a limited number of moving target observations can be scheduled during Cycle 3. Moving targets require special commanding and flight and ground software. They require a high degree of familiarity on the part of the user with the FUSE satellite capabilities. The FUSE Project expects to support a limited number of Solar System observations during Cycle 3, and in general these observations compete for the same resources as other highly constrained observations (see above). Any Solar System observations attempted with FUSE during Cycle 3 must adhere to the *beta* angle constraints discussed in A.1.3.

A.1.4 Data Rights and Distribution

Data rights for FUSE GI observations will reside solely with each observing program's Principal Investigator for a period of six months following delivery of the processed data to the FUSE data archive (http://archive.stsci.edu/fuse). GIs will be notified electronically when their data are available from the archive. After this period, the data become available for public access through the FUSE data archive (see Section A.2.4).

Observations of calibration targets that are not also on GI or PI Team target lists will be released through the FUSE archive as soon as the processed data products are available. The calibration target list may be modified prior to the release of the NRA for future observing cycles. The FUSE Project may use any FUSE observation to assist in assessing the performance of the instrument, but the confidentiality of data obtained for scientific programs will be maintained.

A.1.5 Proposals for Targets of Opportunity

Proposals for major Targets of Opportunity (ToO), such as supernovae, novae, cataclysmic variables in outburst, comets, etc., will be supported in Cycle 3. Scientists wishing to observe such targets should prepare and submit proposals according to the same procedures used for regular program (i.e., as described in the following sections of this Appendix). Note that a proposal must not contain a mixture of ToO targets and non-ToO targets. Target of Opportunity status should be noted in the Special Requirements section of the proposal. The proposals will be reviewed in the regular review cycle, and successful proposals will be approved but will not be allocated specific amounts of observing time. (However, the review panels may recommend a maximum amount of observing time that should be allocated to a given ToO program.) Up to four ToO programs requiring a response time of one month or less will be approved for Cycle 3.

The lack of real-time observing capability constrains the speed with which a ToO observation can be implemented. The FUSE ToO response time may be as short as two days. ToO proposals must clearly state the required response time. It will be the GI's responsibility to notify the FUSE Project Scientist and the FUSE Science Center at JHU when any approved opportunity has occurred. The Project Scientist will consult with the GI, the FUSE PI, and other members of the FUSE Project to determine the feasibility of observing the particular event and the impact of disrupting ongoing observations before deciding whether or not to activate the ToO program and approve the observation.

A.1.6 Discretionary Observing Time

Project Scientist's Discretionary Observing Time is intended for observations of an urgent nature for which no approved observing program exists, which can be accomplished with a small amount of observing time, and which are of sufficiently high scientific merit and priority that they should not be delayed to the next observing cycle. The total amount of Discretionary Observing Time available during Cycle 3 is extremely limited. The FUSE Project Scientist may approve Discretionary Observing Time in those cases where the scientific timeliness of the project is such that it should be done quickly, the need for the observation could not have been foreseen and proposed for in the current observing cycle, and the observation does not duplicate or infringe on approved GI or PI Team programs. A proposal for Discretionary Observing Time may be submitted to the Project Scientist in the form of a letter (printed or electronic) and should describe the observations and their feasibility and scientific objectives, and explain why Discretionary Time should be granted in lieu of consideration during the next proposal cycle. All requests for Discretionary Time will be reviewed for scientific merit and technical feasibility.

A.1.7 FUSE Observers Advisory Committee

The FUSE Observer's Advisory Committee (FOAC) was formed by the FUSE Project Scientist in the spring of 1999. Membership of the FOAC is drawn from the names of Principal Investigators of GI programs. The FOAC meets periodically to advise the Project Scientist on matters concerning the FUSE GI program. See the FUSE GI Program Web site (http://fusewww.gsfc.nasa.gov/fuse/) for the current FOAC membership and minutes of the FOAC meetings.

A.1.8 Targets For Observation

This NRA primarily seeks to identify new targets for observation with the FUSE satellite. The targets reserved by the FUSE PI Team for Cycle 3 are available from the FUSE GI Program Web site. Lists of previously observed targets and those planned for observation in Cycle 2 are also available. Proposers should bear in mind that the FUSE instrument has essentially only one observational mode. Aside from small differences resulting from the choice of aperture, the exposure time alone defines the achievable signal-to-noise ratio for a given spectral resolution for observations of point sources. The target's name and celestial coordinates (RA & DEC in epoch J2000) will be considered when judging any potential target duplications.

- **Target Duplication –** Cycle 3 GI targets may not overlap with those on the PI Team reserved target list. Any duplication of targets between Cycle 3 GI programs and those observed in previous Cycles must be strongly justified in the proposal. The review panels will receive a summary of any duplication between existing observations and those proposed for Cycle 3. The panels will also receive a summary of target duplications between different Cycle 3 proposals. In general, a given target will be allocated to only one observing program.

- **Target List Modifications –** After selection of Cycle 3 GI programs, additional GI and PI Team targets may be added with the approval of the FUSE Project Scientist. Any new target must be consistent with the program's scientific objectives and must not already be allocated to another program.

- **Solar System Targets –** Since Solar System objects are not defined uniquely by a fixed RA and DEC, a different policy applies for defining and protecting the Solar System observations. A GI may propose to observe a Solar System target, even if it has been reserved by the PI Team, if the proposed observation and scientific investigation does not infringe on that planned by the PI Team. The criteria used to differentiate the proposed GI observations from those of the PI Team are the scientific goals and other factors, including aperture size, aperture location on the target, and integration time. GI proposals for reserved Solar System targets should clearly state the differences between the proposed observation and those of the PI Team. The PI Team Solar System observations planned for Cycle 3 are those described in the target lists and abstracts available from the GI Program web site.

- **Targets of Opportunity –** Some Targets of Opportunity may fall into the same category as Solar System objects because their identity and celestial coordinates (RA & DEC) are not known in advance. In this case, a scientific investigation defined by the PI Team would take precedence over a GI proposal with similar objectives.

- **Calibration Targets –** Astronomical targets are used for photometric, flat-field, and wavelength calibration. Most, but probably not all, of the objects listed (see the GI Program Web site) will be observed for calibration purposes. GI's are allowed to include calibration targets as scientific targets in their programs, provided those targets are not also on the PI Team target list. The FUSE Project may continue to use these objects for calibration, even if the target is allocated to a GI or PI Team program.

A.2 The FUSE Mission

A.2.1 Mission Overview

FUSE is a PI-class mission, developed in collaboration with the space agencies of Canada and France. The FUSE Principal Investigator, Dr. Warren Moos of Johns Hopkins University (JHU) in Baltimore, Maryland, is responsible to NASA for the mission design, development, and operations. FUSE is controlled from the FUSE Satellite Control Center located on the JHU campus in Baltimore, Maryland. The FUSE PI is responsible for achieving the primary scientific objectives of the mission. These are the study of (1) the abundance of deuterium in a variety of astrophysical environments, from the local interstellar medium to distant gas clouds along the lines of sight toward quasars and active galactic nuclei, and (2) the amount, distribution, and kinematics of hot gas (as traced by the O VI ion) in the Milky Way disk and halo and in the Magellanic Clouds in order to understand the origin and dynamics of hot gas in these galaxies. These large programs comprise a large fraction of the total time allocated to the PI Team in Cycle 3. Lists of the PI Team reserved targets and science program abstracts are available from the FUSE GI program web site.

The spectral window covered by FUSE permits the study of many astrophysically important atoms, ions, and molecules that cannot otherwise be investigated. This wavelength range is extremely rich in spectral lines arising within the interstellar gas. Proposers are encouraged to take full advantage of the capabilities of FUSE to address important problems in astrophysics. The FUV spectral range provides an opportunity for unique studies of many types of astrophysical objects, such as AGNs and quasars, massive stars, supernova remnants, nebulae, the outer atmospheres of cool stars, planets and their satellites, and comets.

A.2.2 Instrument Overview

FUSE obtains spectra in the 905-1187 Å far-UV band with high resolving power (R~20,000) and high throughput. FUSE has four optical channels, each of which is fed by separate off-axis parabolic mirrors that serve as the primary mirrors for four co-aligned telescopes, all of which simultaneously view the same astronomical field at the same magnification. A Focal Plane Assembly (FPA) is at the focus of each mirror and consists of a flat mirror mounted on a precision two-axis micromotion stage. There are three entrance apertures built into each FPA. The combined effective area of all four channels ranges from ~20 cm^2 to ~70 cm^2, depending on the wavelength.

The high throughput results from the use of an efficient multi-channel optical design and reflective coatings optimized for wavelength coverage in the FUSE range. The spectrograph gratings disperse and refocus the light onto two 2-dimensional delay-line microchannel plate detectors. The entire wavelength range is simultaneously covered on each detector by combining data from two optical channels. Two of the optical channels (one LiF and one SiC) feed one detector, the other LiF and SiC channels feed the other detector. The channels with SiC-coated optics cover ~905-1100 Å, and the channels having LiF-coated optics cover ~990-1185 Å. The resulting spectral images are highly astigmatic in the cross-dispersion direction. Spatially resolved spectral data of limited quality are available only at a few specific wavelengths where this astigmatism is minimized.

Further details on the FUSE instrument can be found the FUSE Observer's Guide, available online at http://fuse.pha.jhu.edu/support/guide/obsguide.html.

A.2.3 Satellite Operations and Observation Planning

FUSE is in a nearly circular orbit with a mean altitude of 768 km, an orbital inclination of 25°, and an orbital period of ~100 minutes. The plane of the orbit precesses with a period of ~60 days. Typically, FUSE is in contact with the ground station for 10-12 minutes per orbit for about seven consecutive orbits, followed by eight orbits (~12 hours) with no contact. All FUSE scientific observations are conducted autonomously by the on-board instrument data system.

One of the main observational constraints is the restrictions in *beta* angle, defined as the angle between the anti-sun direction and the telescope boresight, and is restricted to values between 15˚ and 105˚. However, observations are normally scheduled in the range 30˚ < *beta* < 85˚ in order to maintain coalignment of the four spectroscopic channels. Since the channel alignment is sensitive to changes in the instrument's thermal environment, the *beta* angle constitutes an important scheduling parameter. Observations outside the normal *beta* angle range are possible but must be carefully planned in advance. See Section A.1.3 and the FUSE Observer's Guide for further information.

A.2.4 Data Processing, Calibration, and Distribution

The FUSE data processing pipeline corrects the two-dimensional raw data for instrumental effects and produces one-dimensional, calibrated, extracted spectra. Each exposure produces independent SiC and LiF spectra on each of four detector segments (two segments for each FUSE detector) for a total of eight independent spectra. The data processing system is described in the FUSE Data Handbook (http://fuse.pha.jhu.edu/archive/dhbook.html).

Wavelength calibration maps pixel coordinates into the wavelength domain. The relative wavelength accuracy is presently ~10 km s^{-1}, depending on the channel. Depending on the relative locations with the spectroscopic apertures of the targets used for the dispersion solution and a science target, there can also be a zero-point shift in the wavelength scale. For observations made in the LWRS aperture this offset can be as large as 50 km s^{-1}. The FUSE photometric calibration has an absolute accuracy of ~10% and a rms relative uncertainty of no more than 5%. However, the accuracy realized during an observation depends critically on the stability of the target within the aperture of a particular channel.

The FUSE data are archived at the Multi-Mission Archive at Space Telescope (MAST) at URL http://archive.stsci.edu/fuse/. Access procedures for proprietary and public data are similar to those for Hubble Space Telescope data. Only the PI of each GI program (and their designees) can access that program's data during the proprietary period. The distribution of FUSE data is made by electronic file transfer from the FUSE archive. Observations of calibration targets generally have no proprietary period. See Section A.1.4 for additional information about FUSE data rights.